# Rough Draft for Scientific American

## Teaching An Old Dog New Tricks

by

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The leviathan silently slides through the upper atmosphere of the blue planet, its "eye" steadily staring into the cold, dark recesses of deep space. Periodically the "eye" looks at different points in the blackness while processing the information it "sees". Fourteen thousand kilometers away, another is firing a laser through the atmosphere causing the air molecules to "glow" as the beam slices through the frigid –40 degree Celcius air. Meanwhile, on a neighboring planet, a smaller "offspring" is flying over the surface of the planet, periodically dropping probes to the surface and sampling its atmosphere as it continues its extended journey around the planet. Is this some huge extra-terrestrial creature with large eyes and powerful self-defense mechanism? Is this a planetary invasion by some alien race? In reality, it is mankind's oldest and largest flight vehicle, the balloon, carrying instruments in support of scientific missions.

If this sounds like something out of a science fiction book, it is something that has been the goal and dreams of a group of scientists and engineers in the relatively low profile field of scientific ballooning. Balloons provide a platform for science instruments to study the atmosphere, the universe, the Sun and the near-Earth and space environment. Balloons offer a low-cost, quick-response method for conducting scientific investigations. They are mobile, meaning they can be launched where the scientist needs to conduct the experiment in as little as six months. It has been the training ground for quite a few of today's leading astrophysical and atmospheric scientists. For several decades now, scientific ballooning, has existed in relative obscurity except when being misidentified by the populace as UFOs or alien spaceships. Some of the instruments later become part of the more "glamorous and flashy" spacecraft, orbiting the earth or going out into space. Obscurity has had its advantages. It has enabled scientists to develop, test, modify and refly new science instruments in a fraction of the time and cost as compared to spacecraft. However, this obscurity is beginning to change as NASA continues its implementation of "faster, better, cheaper" philosophy in today's environment of ever shrinking budgets. Scientists and engineers have had to become ever more innovative. NASA has had to consider development of more cost effective means for frequent access to space and near space. This has meant going back and looking at some of the less glamorous science carrier vehicles in the light of new applications and incorporation of newer technologies. For balloons, it is ushering in a new era of applications, mission profiles and technical challenges, and not only on Earth.

### Oldest and Largest Flight Vehicle

Balloons have been in existence for over 200 years. However, the principle that enables the balloon to float was discovered and proved experimentally by Archimedes in 240 BC. He also reasoned that a floating body at rest must displace its own mass of the fluid in which it floats. It is the principle that allows ships to float on water. This principle applies as well to air but man watched smoke rising into the air for the next 2000 years without realizing a practical use. In 1782, the Montgolfier brothers, Joseph and Jacques, floated small paper balloons filled with smoke, at that time called Montgolfier's gas, not recognizing that it was the heat that provided the lifting force. The race was on. 1783 exhibited a flurry of activity. In September of that year, the French Academy of Sciences commissioned J.A.C. Charles (well know for his gas expansion by heat) who sent up a hydrogen filled balloon which flew at approximately 1 kilometer altitude, traveling 24 kilometers in 45 minutes. Later that month a Montgolfier balloon lofted a sheep, a cock and a duck and carried them 3 kilometers in 8 minutes. The first manned flight occurred in November when Pilatre de Rozier and the Marguis d'Arlandes flew in a Montgolfier balloon, replenishing the heat by an on-board straw fire. During its 20 minute flight, the balloon caught fire but was extinguished by the two men with water carried for that contingency. In 1784, scientific atmospheric observations of temperature and moisture were made using a hydrogen filled, varnished fabric balloon. Balloons continued to evolve in design and application. They were generally heavy, being made of coated heavy fabrics therefore limiting flight duration/distance and altitudes to the troposphere. Balloons were often used for shows and national prestige. They were also used by the military such as during the United States Civil War and bomb laden German Zeppelins during World War II. Another little known event occurred in 1943-1944 when the Japanese released approximately 9000 paper balloons carrying bombs across the Pacific Ocean towards the United States. Approximately 10% reached North America with most doing little damage. In the late 1940s and early 1950s the United States Navy sponsored the development of balloons using polyethylene. This work ushered in the era of modern day ballooning. Balloons were able to reach the stratosphere, carry more payload for longer duration and distance. They also became the early version of the "spy plane and spy satellite". Manned flight altitude records and studies using balloons were conducted as precursors to the United States manned entry into space. Balloons increasingly served as platforms for atmospheric, astronomical and astrophysical science observatories. In 1960, the first balloon satellite called Echo I was launched by rocket into space by NASA. The French also pioneered the use of balloons to explore other atmospheres. In 1985 an international team, led by the former Soviet Union with assistance by CNES, the French Space Agency, built and successfully flew two balloons in the clouds of Venus, 54 kilometers above its hot surface. Each flew for about 46.5 hours, and traveled more than a third of the way around the planet. Today, balloons continue to fill the gap between where present day powered aircraft and satellites cannot operate. Several countries continue to have scientific balloon programs as integral parts of their science programs.

Balloons also have the distinction of being man's largest flight vehicle. NASA's conventional scientific balloons are constructed of 20 micron (0.0008 inches) thick, polyethylene film (about the same thickness as ordinary sandwich wrap). Balloons are fabricated by cutting 2.75 meter wide by several hundred meter long sheets of polyethylene film to a preset pattern,called a gore, as determined by analysis. Another layer of film is then dispensed, cut, sealed with the edge of the preceding gore and then stacked on top of the previous gore. This process is repeated until the correct number of gores have been sealed together such that when fully inflated, the balloon has the designed shape and volume. An analogy would be a banana where the individual pieces of the peel would be the gore and when all of the pieces of the peel are connected together, they form the shape of a banana. A large balloon may contain as many as 180-200 gores and seams, each being over 200 meters long. They have volumes up to 1.1 million cubic meters (~ 39 million cubic feet). (Modified Gee Whiz Figure). The largest successful balloon had a volume of 1.49 million cubic meters. A typical balloon can contain as many as 90,000 square meters (22 acres) of film and 22 kilometers of seams. Scientific balloons routinely carry payloads weighing as much as 3,630 kilograms (about the weight of three small cars) to 36.5 kilometers, although heavier payloads have been flown at lower altitudes. Although the altitude record achieved by a scientific balloon is 51.8 kilometers (set by the Air Force), NASA's balloons normally float at an altitude of 35-40 kilometers.

**Applications**

Balloons have been the tool to achieve three important objectives: 1) to study directly, with *in-situ* measurements the structure, composition and chemistry of the earth's atmosphere, 2) to detect electromagnetic radiation from sub-millimeter to gamma-ray wavelengths, high energy particles (cosmic rays) and particulates from extra-terrestrial sources that cannot penetrate the earth's lower atmosphere and 3) to serve as a delivery system, launch platform or observational platform. Although spacecraft offer long observational times, the opportunities are very limited, costly, with long lead times and limited mass and volume except for the Space Shuttle. Balloon-borne experiments still provide a rapid response to targets of opportunity. This is exemplified by the very successful balloon observations from Australia of Supernova 1987A at X-ray and gamma-ray wavelengths within 3 months of its discovery. Another important aspect of scientific ballooning in the space age has been the development and testing of space-flight instrumentation. One such example is that many of the instruments which were flown on the Cosmic Background Explorer (COBE) were first developed, tested and used for observational purposes on balloon missions.

A balloon mission begins when the balloon is partially filled with helium and launched with a payload suspended beneath it. As the balloon rises, the helium expands and fills out the balloon until it reaches its peak altitude two to three hours after launch. After the scientist has concluded the experiment, a radio command is sent from a ground station to separate the payload from the balloon. The parachute opens and floats the payload back to the earth' surface so it can be reused. The payload reaches the ground about 45 minutes after it has been separated from the balloon. The payload is recovered, often to be used again. The balloon, destroyed by the payload release, falls back to earth, is retrieved and discarded.

The demand for balloons is not just on Earth. Balloons are also gaining in acceptance for use on planetary missions, performing tasks unable to be accomplished by surface rovers and orbiting spacecraft. Led by NASA's Jet Propulsion Laboratory (JPL), concepts using balloons are being developed and tested for the exploration of Mars, Venus, Jupiter, Saturn, Uranus, Neptune and Saturn's moon Titan. Planetary science wanting use of balloons generally are interested in atmospheric chemistry and dynamics, paleomagnetic mapping, geological reconnaissance and ultra-high resolution imaging. Both of these efforts have created a synergistic effect and a revitalization for the use of balloons as a cost-effective means of conducting space research and performing tasks that surface rovers, aircraft or orbiting spacecraft cannot accomplish. Both want 'longer". As a result, new emphasis has been placed on the development of materials and balloon vehicles that can fly longer in a wider range of environments.

## A Super Balloon

In 1997 a project was approved by NASA's Office of Space Science to develop and demonstrate a new scientific balloon capability roughly an order of magnitude greater in capability to support science missions lasting up to 100 days above 99% (density < 10 gm/cm$^3$) of the earth's atmosphere. The project, called the Ultra Long Duration Balloon (ULDB) Project, is managed by NASA's Goddard Space Flight Center (GSFC) -Wallops Flight Facility (WFF) as part of the NASA Balloon Program. The ULDB project is developing new composite materials and a new balloon design, a standard gondola including power, global telemetry/command and an altitude control system. The ULDB is seeking to improve mission control and operations and the integration of the scientific instruments. It is the "longer" that has been the driver for the resurgence of interest in balloons by the scientific community. In recent years, the manned global ballooning attempts have called attention to the difficulty of achieving "longer". The promise of ULDB has convinced the relevant NASA Headquarters science managers that ULDB can in some instances provide a science return approaching that of some spacecraft. This has been evidenced by the inclusion of balloon missions in the first University-class Explorer (UNEX) Announcement of Opportunity released by NASA on January 1998.

The technological developments that have most affected present day balloon design are the development of stronger and lighter plastics, computers and advancements in balloon structural design. In fact, the forgiving nature of the polyethylene has undoubtedly contributed to the amount of success experienced in conventional scientific balloons. Much of the design work was accomplished with sweeping engineering assumptions since analytical tools were not up to the challenge of a non-linear structure fabricated from a non-linear material. Balloons were assumed to be rotationally or axially symmetric with zero circumferential or hoop stress. The mechanical properties of the structural envelope were generally unknown and as a result were usually ignored. It has been only within the last two decades that advanced computers and numerical methods for structural analysis, materials characterization and radiative heat transfer have made the problem tractable.

Scientific balloons generally fall into two categories: the zero-pressure and the super-pressure. Zero-pressure balloons are generally fabricated of polyethylene film whereas super-pressure balloons have generally been fabricated of polyester film. The conventional scientific balloon of today is called the zero-pressure balloon and uses helium as the lift gas. A zero-pressure balloon is an "open" system. The balloon is inflated with enough helium such that the buoyant lift force is greater than the total system mass of the balloon and the payload combined. The excess lift force is called "free lift" in ballooning terminology and provides the forcing function to get the balloon to the desired float altitude. The volume of the gas in the balloon is only a small fraction of the gas volume at altitude. As the balloon rises through the atmosphere, the atmospheric density decreases and the gas inside the balloon increases until the balloon becomes completely filled. Once filled, the excess is vented out of vent ducts, or holes at the base of the balloon, maintaining a zero differential pressure at the base of the balloon. This is to prevent rupturing of the relatively low strength and stiffness polyethylene envelope. Gas continues to be vented as the daytime sun continues to heat the gas. At sunset, the amount of solar heating decreases, the gas cools, the volume contracts and the balloon starts to descend to a lower equilibrium altitude during the night. To maintain altitude, one must drop system mass, called ballast nominally amounting to 7-10% of the total system mass. This means dropping of mass from the suspended payload, usually in the form of very fine steel powder of glass. The next day, the sun again heats the gas and the balloon rises until it becomes full once more, vents gas and repeats the cycle. One can quickly see that soon no payload will be remaining thereby limiting the amount of flight time to just a few days at the desired float altitude. The flight must then be terminated. Typical scientific balloon flights last an average of 1-2 days often necessitating multiple flights to obtain enough statistical scientific data. One method of "cheating" this losing proposition is to fly in the polar regions in perpetual daylight or darkness. NASA currently conducts a limited number of flights from Fairbanks, Alaska and McMurdo Station, Antarctica where the constant daylight during the local summer allows extension of the flight for up to 2-3 weeks in duration. However, only a limited number of scientific disciplines can take advantage of this. The cry from the scientific community has been for longer flights on a global basis.

Super-pressure balloons are "closed" systems meaning they are not vented to the atmosphere and are generally spherical in shape. They are usually fabricated from higher strength and modulas polyester film. They are inflated like the zero-pressure balloons however, once they get to altitude the balloon becomes filled and the internal pressure continues to increase until it exceeds the outside ambient pressure and has a positive differential pressure. The differential pressure continues to increase as the sun continues to heat the gas. At night, the gas cools and the differential pressure decreases. If enough gas has been put into the balloon, the differential pressure will never drop below zero. The balloon will remain full and at altitude without having to drop ballast. Any change in altitude is a function of the modulas of the balloon envelope and how much it "stretched" under pressure and the amount of gas in the balloon. As can be seen, much longer duration is achievable as long as the integrity of the envelope is maintained. Small, spherical super-pressure balloons made of polyester film have flown for up to several hundred days but at much lower altitudes. In the 1970's attempts were made to scale these balloons up to larger volumes for heavier payloads and higher altitudes. Problems were identified with intrinsic properties of the polyester films, namely material defects and effectively zero tear strength. This prevented scale up with any degree of reliability.

The balloon is a thermal vehicle and its thermal inputs vary over time. The energy balance is a function of the thermal (heat) load on the object and the coupling of that object to its environment. The thermal loads include direct and reflected sunlight off of the planet and internally generated heat. Heat is rejected by radiation to space or to/from the planet. The total balance also includes convection between the gas and film, air and film and the radiation between the gas and film. At 35-40 kilometers, nearly all energy interchange external to the balloon is via radiation.

The above conditions establish the operating differential pressures required to maintain the super-pressure's full volume under the most extreme set of environmental conditions (overflight of oceans, hot deserts, polar ice caps, etc.) on a global flight lasting several months. This established a material strength requirement of approximately 5300 Newtons/meter (30.3 lb/in) for a spherical super-pressure design. (A black balloon will run much hotter than one that is white.) Other properties must also be considered. The material must be able to withstand ground launch temperatures approaching 40 degrees Celcius and ascent temperatures through the atmosphere of –90 degrees Celcius. It must have good fracture and tear toughness, excellent strength, modulus and creep characteristics, low permeability, pinholing resistance, ultra-violet degradation resistance and be capable of being manufactured into a balloon at a reasonable cost.

It was concluded that the best approach would be to develop a composite material, taking advantage of desirable properties that different materials offered to offset deficiencies in the other components. Many different materials were evaluated including films, woven fabrics, non-wovens (spun-bonded), and scrims of polyester, polyethylene, nylon, polypropylene and composites of these. Several prototype materials were fabricated, tested in the laboratory and built into test structures and test balloons. A material designated as DP6611.25 was selected. DP6611.25 (material composition figure) is composed of a 30 denier, high tenacity polyester fabric woven in Japan, 6 micron DuPont mylar® film and 6 micron Stratofilm-372® film manufactured in the United States. The three layers are adhesively laminated together with a "soft" adhesive here in the United States as well. It has a density of 62 grams/square meter with an ultimate and "yield" strength of 7600 and 2600 Newtons/meter (14.8 pounds/inch) respectively. The mylar serves as the primary substrate and gas barrier. The polyester fabric serves as the primary strength member and provides tear toughness. The polyethylene serves as an additional gas barrier and provides extra fracture toughness. Because of polyethylene's excellent elongation properties, it compensates for any material defects while maintaining gas barrier integrity. The polyester fabric and mylar were chosen because of superior UV degradation as compared to several of the other materials evaluated although degradation still does occur. The "soft" adhesive, while bonding the various layers together, allow for some realignment of fabric fibers to compensate for any weave defects or adjustment to different loading conditions.

Even with the improved material, it was felt an inadequate margin of safety existed for a spherical balloon design and end of life properties. As a result, different balloon shapes and structures were considered to reduce the stress levels in the envelope material. Building upon previous and on-going balloon design work in Japan, France and the United States, a new design was generated departing from the conventional mode of spherical super-pressure balloons. In a spherical super-pressure balloon, the balloon envelope carries most of the global load resulting in both meridional and circumferential stresses. This often exceeds the ability of the envelope material. The structure chosen for the ULDB is most commonly called the "pumpkin" because of its shape. (Photo of spherical & pumpkin balloon). The concept is based on three basic premises: 1) a mono-dimensional structure or load tendon that carries the largest fraction of the global load, 2) an envelope material who's strength is significantly lower than that of the load tendon and 3) an envelope material that is compliant for relief of any high localized stresses. For the ULDB "pumpkin" design, the load tendon minimum strength requirement is approximately 7 kilonewtons (1574 pounds) without a safety factor. The load tendons are longer than the envelope gore length such that there is a mis-match between the gore and the tendon. This allows the tendon to carry most of the meridional load, off-loading the envelope material. In the circumferential direction, loads are reduced by altering the shape to an oblate spheroid and allowing the envelope to lobe. The lobing reduces the local radius of curvature, thereby reducing the load in the envelope material. As a result of this approach, film strength requirements were reduced from a value of 5300 Newtons/meter for a spherical balloon shape to 600 Newtons/meter, almost a factor of 10; well within acceptable limits and below the "yield" of 2600 Newtons/meter. In implementation, the load tendons are made of poly-benzobisoxazole

(PBO) fiber manufactured in Japan. PBO has superior tensile strength and modulas compared to steel and poly-aramid fibers (kevlar) as well as excellent thermal stability.

The ULDB is scheduled to be flown in the Southern Hemisphere in December 2000 from either Australia or New Zealand. The balloon will be "pumpkin" shaped with a volume of 731,244 cubic meters. It is 78.6 meters high by 128.3 meters in diameter. It contains 268 seams for a total seam length of slightly over 45 kilometers. The science instrument is a cosmic ray payload called the Trans Iron Galactic Recorder (TIGER). TIGER is designed to measure the abundances of all elements in the Galactic Cosmic Rays (GCR) with $26 \leq Z \leq 40$ and energies above 300 MeV/nucleon. This will be the first time the abundances of the odd-Z elements between Z=28 and Z=40 have been measured. The nuclei are of great interest since they include a sample of galactic matter either freshly synthesized in super-nova or representative of the interstellar medium.

## Extra-Terrestrials

Scientific balloons also are emerging to play a key role in the exploration of the planets. Six planets – Mars, Venus, Jupiter, Saturn, Uranus and Neptune and Saturn's moon Titan have sufficient atmosphere to permit a balloon to fly. However, the challenges and opportunities of balloon flight in each atmosphere are different. Balloons may be used to study the composition and circulation of the atmosphere. For the three bodies with solid or liquid surfaces – Mars, Venus and Titan – they may also be used to study those surfaces. They can be used as platforms for remote sensing or in situ sensing exploration, vehicles for precision deployment of probes, platforms for relaying communications between other payload elements and as a means for acquiring surface samples for return to Earth.

**Mars:** The exploration of Mars bears perhaps the closest analogy to scientific ballooning in the Earth's stratosphere. The atmospheric density at mean Martian sea level is only 10 g/m$^3$ – about what it is in the Earth's stratosphere at 35 km. Thus a balloon operating a few kilometers from the surface of Mars must be designed like a terrestrial stratospheric balloon. It is possible to design super-pressure balloons for Mars that will remain aloft for months.

Such an aerial platform can plays a key role bridging the gap in spatial resolution and coverage between the observations that can be made from Mars orbit and those that can be acquired by a rover on the Martian surface. The balloon does not have the global reach of the satellite but it is more than a hundred times closer to the surface and it can make observations of remnant magnetism and subsurface water that are simply not feasible from orbit. Although a rover may obtain higher resolution observation, the balloon travels thousands of times farther than a rover could travel in an equivalent time.

In the late 1980s, Russia and France collaborated on the Mars Aerostat mission, an ambitious mission equipped with both a scientific gondola with an imaging system and a guiderope that draped on the surface of the planet acquiring chemical and physical measurements. The Mars Aerostat mission was cancelled in 1995 because of Russia's financial problems. In 1997, NASA began work on some of the key technologies needed for a much smaller Mars balloon benefiting from the experience of CNES, the French Space Agency. One of the principal accomplishments of this effort has been the development of a more mass efficient aerial inflation that introduces helium gas from beneath the balloon rather than from above it (Figure). Another has been the demonstration of aerial inflation of a solar Montgolfiere balloon – a type of balloon that is filled with ambient atmosphere and relies on solar heating of the balloon for buoyancy. (Figure)

**Venus:** In 1985, the Soviet Union led the first balloon mission to Venus in collaboration with France and the United States. Venus, Earth's sister planet of comparable size but closer to the Sun has a very thick atmosphere, composed primarily of carbon dioxide with a surface pressure more than 90 times that of the Earth and a surface temperature of 460C. Two Venus Vega balloons were successfully deployed in the atmosphere of Venus at an altitude of 56 km and each operated for about 48 hours travelling half way around the planet confirming the existence of very strong high altitude winds. Temperature and pressure were measured by instruments in the balloon gondola. NASA coordinated a network of global tracking stations to measure the position and velocities of the two balloons.

Future balloon-based exploration of Venus will focus intensively on the surface of Venus. The thick atmosphere makes it impossible to image the surface of the planet from space except at radio wavelengths. The high temperatures at the surface make it impractical to deploy surface vehicles capable of lasting more than a few hours.

Balloons play many roles. One concept is the Venus Volcanic and Atmospheric (VEVA) mission. An aerobot, drifting in the cool upper reaches of the atmosphere, deploys a number of very small probes or "sondes" to the surface to obtain high-resolution images and spectroscopic data that could help unlock the secrets of the evolution of Venus. From a deployment altitude of about 55 km, the sondes can be targeted quite precisely to the surface features of interest and efficiently recover data from the sondes and store it on the aerobot before returning it to Earth.

Aerobots that can make trips of relatively short duration – perhaps a few hours – to the surface of Venus can also play an important role in Venus exploration. Such a vehicle might carry a powerful suite of instruments to the surface and explore the surface in much the same fashion as deep-sea submersibles have explored the floor of the deep ocean. A concept for a "reversible-fluid" aerobot, capable of making repeated visits to the surface of Venus was demonstrated at JPL in 1995. Some key technologies including PBO balloon materials tolerant of the high surface temperatures and sulfuric acid clouds on Venus and a miniature gondola capable of tolerating the temperature and the pressure for several hours of surface operation have been developed.

Major steps forward in the understanding of Venus will only be possible if rock samples from the surface can be returned to Earth. Two teams studying such a Venus Sample Return mission, one at the European Space Agency and the other a NASA team at JPL, both agree that this could only be achieved using a balloon to lift material from the surface to an altitude of about 60 km. From that altitude, the sample would be launched on a rocket called a Venus Ascent Vehicle (VAV) into Venus orbit and from there the sample would be transferred to another spacecraft and returned to Earth. Many important details of the Venus Sample Return mission are still being investigated – one important issue is whether the rocket should be carried to the hot surface with the sampling device or rendezvous with the sampling balloon at altitude. Some ingenious approaches have been developed but the optimal mission architecture has likely not yet emerged.

**Titan:** Saturn's moon Titan has become a primary target for solar system exploration motivated by the search for evidence of prebiotic activity. Photochemical reactions in the atmosphere of Titan appear to be generating organic materials some of which form an orange haze which masked the surface from view when the Voyage spacecraft flew close by Titan in the 1980s. It was once thought that Titan might have a global ocean of liquid hydrocarbons beneath this haze. It is now known that there are fixed surface features and evidence of variable low altitude clouds. Titan now appears to be a heterogeneous world perhaps consisting of large seas of hydrocarbons as well as areas of solid surface. Atmospheric conditions on Titan are very favorable for balloon flight and aerial platforms provide an ideal way of exploring the planet.

The atmosphere of Titan, which is predominantly nitrogen, is almost five times as dense as that at sea level on the Earth but extremely cold – just warm enough to prevent the atmosphere from liquefying. Even a small balloon can carry quite a large payload. There are many ways to modulate the lift of such a small balloon using the radioisotopic heat sources that are used for power in the outer solar system and make multiple descents for close observations of the surface.

In 2005, the Huygens probe developed by the European Space Agency will be detached from NASA's Cassini spacecraft and descend into the atmosphere of Titan. As it descends toward the surface if will the first pictures beneath the haze layer of the surface of Titan of an area a few tens of kilometers across. If the Huygens probe survives impact with the surface of Titan and lands on a liquid surface it is also equipped to measure the composition of that liquid.

A Titan aerobot mission that follows the Huygens probe could traverse thousands of kilometers making surveys of surface features that cannot be made from orbit (except with radar) because of the obscuring haze. It can descend repeatedly to acquire very high-resolution observations, and when the major categories of feature are known it can deploy surface sampling systems to make direct surface observations. In the very distant future we can imagine deploying a Titan Ascent Vehicle to return samples of prebiotic material to Earth.

## Technology for Planetary Balloons

Just as technology has played a key role in the rebirth of stratospheric ballooning so it is also played a vital role in opening up the solar system to balloon exploration. There are many similarities but also some differences in the role that technology is playing in the two cases.

New balloon envelope technologies are vitally important in all applications. Stronger membrane materials make possible weight savings in envelopes that can be converted into additional payload mass. The impact is largest with super-pressure envelopes used in the stratospheric ULDB and for aerobot and airships for Mars, Venus and potentially Titan. The severe environments encountered in some planetary applications particularly Venus with its high surface temperatures and sulfuric acid clouds represent a major challenge.

New methods of both predicting and controlling the flight path of buoyant vehicles with minimal energy usage are also vitally important. Schemes for utilizing vertical differences in wind velocity with height are being studied. For long duration stratospheric balloons the motivation is to avoid over-flights of sensitive areas of the worlds and to move payloads from one hemisphere to another as the seasons change. For planetary missions, the objectives are achieving over-flights of interesting targets and extending the flight path of the balloon from a narrow latitude belt to a larger part of the planet.

It should be recognized that the kind of instrumentation that we want to fly on stratospheric balloons and planetary balloons are quite different. A major focus of stratospheric ballooning involves astrophysical observations. Conceptually, the balloon acts like an enormously high mountain with its peak extending above 99% of the atmosphere. To collect scarce photons from deep in the universe the instruments must be very large perhaps physically much larger than could be carried into space. In contrast, for planetary ballooning, instruments can be small because the balloon makes it possible to make close approaches to the target of interest. Mass and volume is also very costly for a planetary exploration system and so there is a great drive for miniature instruments and avionics. NASA's X-2000 technology program is now developing avionics tightly a "spacecraft-on-a-chip" and this will have enormous impact on the future capabilities of planetary balloon missions.

Another distinction is that on the Earth, balloons are typically launched from the surface and then rise to their operational altitude. A planetary balloon, in contrast, must enter the planetary atmosphere packaged in an entry capsule and then deploys and inflates during descent through the atmosphere. Efforts are now underway to develop simple robust systems for deployment and inflation. A target is to get somewhere between 10 and 20% of the entry mass into balloon payload.

## Conclusion

The rebirth of ballooning is now well underway. During the next decade the ULDB will be expanded to even beyond those currently planned and provide a new capability for long term access to space. In the same time frame balloon missions to Mars, Venus and possibly Titan will be contributing to a remarkable expansion in our knowledge of the solar system. Who says you can't teach an old dog new tricks?

## POSSIBLE ILLUSTRATIONS:

1. Modifications of existing pictures of a Mars Aerobot or a Venus Aerobot.

2. Illustration of the VEVA mission showing deployment of probes from a balloon to the surface of Venus.

3. Illustration of a Venus Sample Return mission with a balloon rising from the surface and performing a rendezvous with a blimp.

4. Actual pictures showing the Earth tests of a Mars balloon deployment